TMO TECHNOLOGY DEVELOPMENT PLAN

Communications Systems Analysis Work Area

Work Area Manager: Fabrizio Pollara
Phone: (818) 354-4287
Email: fabrizio@shannon.jpl.nasa.gov

Program: Data Services
Mail Stop: 238-420
Fax: (818) 354-6825

OBJECTIVE:

Develop innovative information technologies to enable future missions at lower cost and with higher scientific returns. This effort is focused on improving space communication capability at low cost through research, analysis and development in key areas of channel coding and overall communication system performance.

GOALS and SIGNIFICANCE:

1. Develop error-correcting coding and modulation schemes for future deep-space missions, and provide new methods for telemetry data processing. This work area will continue to exert leadership in channel coding for deep-space communications and to provide accurate performance analysis of coding schemes. It will develop new, higher performance or lower complexity schemes, for both RF and optical links, and influence code selections by CCSDS and other space agencies. Define communication link protocols suitable for new channel codes and for applications to links with long round-trip delays.

2. Develop decoder architectures. Coding and decoding concepts will be demonstrated, and designs suitable for implementation with current technology at low cost will be developed.

3. Perform system analysis to characterize expected operational performance and evaluate technology alternatives for future deep space communications. Develop, maintain, and analyze data on new technologies (performance, costs, uncertainties, and risks) and potential future flight project needs in order to: characterize the expected operational performance of future DSN systems, especially Ka-band and optical; evaluate technology alternatives and identify potential improvements; support flight demonstrations of advanced systems and technologies; and identify additional DSN capabilities and performance improvements to enable or enhance smaller, faster, and cheaper missions.

The complexity and cost of many present deep-space telemetry links are dominated by antenna size on the spacecraft and on the ground, by available power on the spacecraft, and by DSN operations costs. Future small missions will require very efficient communication systems. Information theory, error-correction coding, and advanced modulation techniques can provide a cheaper alternative to larger antennas or heavier, more powerful spacecraft by pushing the communication channel closer to its theoretical capacity while still guaranteeing high reliability. Efficiency is obtained by protecting the data with powerful error-correcting codes (channel coding), by using advanced modulation techniques that are both power and bandwidth efficient, and by using communication strategies that simplify DSN operations.

System analysis provides the technical foundation for tradeoffs involving costs, benefits, and risks associated with new DSN communication systems and new technologies (e.g., Ka-band can reduce mass by 20-30% and power by 30-45%, for Mars missions transmitting 1-10 Gbit/day). In order to achieve and demonstrate improvements in complex missions, careful system-level planning, link analysis, study of atmospheric data, and evaluation of technology alternatives for future DSN microwave systems are needed. Particular emphasis is placed on Ka-band technology, which has 4-6 dB link performance advantage over present X-band links. Specific DSN telecom issues that need system analysis include: potential improvements offered by new technologies in telecommunication systems, telemetry and radiometric data; possible future DSN architectures and capabilities which will best support future missions; comparative evaluation of candidate telecom options; development and analysis of robust Ka-band operations concepts which address atmospheric-induced variability in link performance.

The net results of the methods considered in this work area are higher science returns at lower cost than by using alternative technologies, thus enabling lower cost missions. The work area also finds and demonstrates better uses of

current telemetry systems and recommends changes. New designs and ideas are structured for timely transfer from this work area to DSN implementation. This will be useful to maximize the return of NASA's technology investments.

PRODUCTS:
- New error-correcting coding and modulation schemes for future deep-space missions (higher performance and/or lower complexity)
- New methods for telemetry data processing
- New coding standards for CCSDS
- Decoder architectures for timely transfer to DSN implementation
- Accurate prediction of coding systems performance and coding demonstrations
- Advanced strategies for improvement of communication link performance
- End-to-end system analysis (Ka-band and optical) to characterize the expected operational performance of future DSN systems

DESCRIPTION:
Channel coding is a proven cost effective method for reliable communication. There is a continuing need to provide accurate performance analyses of coding schemes, and to develop higher performance and/or lower complexity new schemes. Such improved coding systems for deep-space missions were identified in FY96, based on the recent breakthroughs in turbo codes. It is realistic to project that in two years turbo codes will achieve about 1 dB improvement over the best codes currently in use in the DSN, with an even more important reduction in decoding complexity of about one order of magnitude. This work area is also supporting the standardization of these new codes through CCSDS.

There is a need to develop efficient implementations of turbo decoders to achieve the complexity savings predicted by theory, and to benchmark the performance (speed, power efficiency, bit and frame error rates) of new turbo coding systems. It is also necessary to understand the error characteristics of turbo decoders, which are different from those of Reed-Solomon/convolutional concatenated coding systems. It is important for users to understand these characteristics and how they might affect their data.   Additional simulations are needed to investigate the decoder error statistics in more detail than simply measuring the average bit error rate.   There is also a need to develop methods for certifying data integrity after turbo decoding.

Analytic performance bounds are needed to verify and extend simulation results at very low error rates, especially for frame error rates. New theoretical work on tightening the performance bounds can potentially yield similarly valuable insights into turbo code behavior in the "waterfall" region of the performance curve.

The inherent low complexity of turbo encoders and decoders allows rapid implementation development. Such rapid implementation will make the performance and complexity gains from turbo codes available to near-future missions. This work area has developed both an efficient software decoder and an FPGA prototype hardware decoder, and is investigating various important performance/complexity tradeoffs that affect these implementations.

The approach in channel coding is to forge ahead in our theoretical understanding of turbo codes and turbo decoders, while at the same time developing software decoding algorithms and adding new features to the hardware FPGA decoder prototype. Specific plans for FY98 are:

1. Demonstrate FPGA turbo decoder prototype, including frame synchronization in the symbol domain. Use decoder prototype to acquire data on error statistics and produce detailed histograms. Determine frame error rates as well as bit error rates. Determine dependence of performance on the code block length and on the number of iterations. Propose and analyze an outer code to correct and/or detect residual turbo decoder errors. Benchmark speed/performance of variations of decoder prototype, define final architectural design for network infusion, and partner with industry to commercialize.

2. Analyze system issues for turbo codes. Develop methods for certifying data integrity after turbo decoding. Analyze and test (via software simulation or TDL) turbo decoders with various levels of timing and phase jitter. Study effects of SNR estimation errors on performance. Develop fast algorithms for on-the-fly permutation generation. Develop improved frame synchronization methods. Determine turbo decoder behavior when the noise is not additive white Gaussian. Develop turbo decoders that are adaptable or robust to unanticipated noise sources.

3. Applications of turbo codes. Study the applicability of turbo codes to optical channels and compare performance with Reed-Solomon codes. Develop turbo codes for short-block applications: emergency mode communication and short-lived probes.

4. Continue to develop theoretical bounds on the performance of turbo codes. Modify the code geometry bounds developed in this work area to tighten current bounds in the "waterfall" region of the performance curve. Propose autonomous turbo decoder stopping rules and determine their effectiveness. Start developing a unified theoretical understanding of turbo codes and their variants (parallel, serial, hybrid, self-concatenated, short/long block, etc.). Determine block sizes for which turbo codes are preferable to conventional non-iteratively-decoded codes.

This work area will also develop suitable decoder architectures, which can be implemented with current technology at low cost. In FY97 we have developed an FPGA-based turbo decoder that can decode (parallel) turbo codes with two component codes, each up to 64 states, up to 64 Kbits long input blocks, and code rates 1/2, 1/3, 1/4, and 1/5. This year we will benchmark speed and performance of the decoder prototype. We plan to extend the decoder design to serially concatenated codes, to use the existing decoder as a research tool to acquire error statistics, and compute bit and frame error rates for many turbo codes. We will also analyze very low complexity turbo codes/decoders for on-board applications.

The end-to-end analysis effort will focus on establishing and maintaining a body of data on new systems, technologies, and potential DSN needs; developing models to characterize and project operational performance of present and future systems; performing comparative analysis to evaluate alternative technologies and identify potential DSN improvements; and supporting advanced mission studies and developing operational strategies to facilitate adoption of advanced technologies.   In FY98 we plan to continue the comparative analysis of Ka-band and X-band system performance and operations. We also plan to develop Ka-band operations concept providing low-cost, highly operable, robust, high-performance downlink telemetry service. There is a need to study the effects of scintillation at Ka-band since many current and future missions encounter solar conjunction. Scintillation is an important concern not only for telemetry but, also for radio metrics and navigation.   Antenna pointing accuracy is a concern when operating at Ka-band, and the existing pointing techniques need to be assessed for their advantages and disadvantages. The impact of oscillator phase noise at Ka-band needs to be quantified. New transmission strategies based on weather models need to be developed for Ka-band. Telecom performance and cost assessment will serve strategic planners in TMOD and future flight projects. The updated system parameters will keep mission planners and telecom system engineers informed of the latest DSN capabilities. Finally, we plan to support the development of LinkScape (a software tool for communication link design) by creating a database containing DSN parameters (system temperature, antenna apertures and efficiencies, etc.), and by developing analysis tools to assess the cost and performance of DSN improvements.

In the three years beyond 98, we plan to:
- Improve efficiency of deep-space link by a factor of ten by using integrated data compression and channel coding systems, better telecom strategies (retransmission integrated with progressive transmission, planetary telecom relay orbiters, coding/modulation for optical communications).
- Devise new decoding structures to take full advantage of complexity reduction offered by turbo codes at performance close to channel capacity. Implement prototypes and demonstrate performance on real channel.
- Develop low-cost/intelligent/user-friendly telemetry ground processing by using reprogrammable hardware. (This also reduces development, operation, maintenance, upgrading costs).
- Continue our analysis of new and existing channel coding schemes.
- Perform system level tradeoffs for advanced communication strategies.
- Maintain and expand the link design and analysis software tool. Expand and promote its use for preliminary analyses by Team-X/PDC/Design Hub. Maintain a set of telecom strategies for generic missions (flybys, orbiters, etc.). Include more accurate performance analysis/prediction, reduce uncertainties. Add capability for obtaining error estimates and uncertainties (distribution of error) on computed quantities.
- Completely specify re-transmission protocols and demonstrate on a low data rate mission with large on-board storage. (FY99)
- Integrate progressive transmission and re-transmission schemes. (FY00)
- Demonstrate an end-to-end source and channel coded system designed by joint optimization of source and channel encoders. (FY00)
- Continue telecom analysis, data collection and modeling, and system studies to better characterize Ka-band link performance, to reduce link uncertainties, and identify future missions for which Ka-band can provide significant

cost and/or performance benefits. Update models by incorporating results of MGS, NM-DS1 and Cassini. (FY99+).
- Conduct system studies to develop possible system architecture and identify new technologies needed to meet the telecommunication needs of future high-rate, near-earth science missions as well as deep-space missions (FY99).

Our long-range vision for this work area is to:
- Continue to influence the design of new missions, and enable lower cost missions.
- Develop codes for higher data rates while meeting new stringent spectrum limitations.
- Conduct system studies to identify and provide solutions to overcome challenges posed by future generations of cheaper and smaller spacecraft.
- Provide a database that can be used to guide future development and operations of the DSN in an ever changing environment (e.g., possible reallocation of the S-band spectrum, the implementation of Ka-band, the emerging optical technologies, the deployment of fully automated small earth terminals, the development of direct-to-user data distribution architecture, etc.).
- Develop an overall DSN telecom system simulation.
- Define best strategy/modulation/coding for emergency comm. at Ka-band and optical. emergency communications. (Cross-disciplinary with steerable array antennas).
- Develop light-weight, space qualified BPSK orbiter/lander transceiver (modulation/coding).
- Develop space qualified turbo decoder for orbiter/lander telecom and for uplink commands
- Develop methods to protect on-board processing in high radiation environments.
- Develop low cost ground telemetry processing using reconfigurable (FPGA-based) systems, especially for new optical receiving stations.

DELIVERABLES:
Channel Coding:
- Identify suitable serially concatenated codes and analyze their performance.
- Resolve system issues: Develop methods for certifying data integrity after turbo decoding; Study effects of SNR estimation errors on performance; Develop fast algorithms for on-the-fly permutation generation; Develop improved frame synchronization methods; Develop turbo decoders that are adaptable to unanticipated noise sources; Develop turbo codes for short-block applications
- Develop improved theoretical bounds on the performance of turbo codes
- Study the applicability of turbo codes to optical channels
- Develop turbo codes for very high data rates
- Support CCSDS activities for standardization of turbo codes
- Support turbo coding experiments (Cassini, New Millennium DS1)

Decoder Development:
- Demonstrate FPGA turbo decoder prototype: Benchmark speed/performance of decoder prototype; Use prototype to acquire error statistics, and compute bit and frame error rates; Propose and analyze an outer code.
- Partner with industry to commercialize prototype.
- Analyze very low complexity (2+2 states) turbo code/decoders for on-board applications.

End-to-End Systems Analysis:
- Continue comparative analysis of Ka-band and X-band system
- Continue study of scintillation effects on telemetry performance --- Extend scintillation model to radiometrics at Ka-band and X-band
- Assess G/T versus SNR for different antenna pointing techniques --- Determine system loss (how pointing affects G/T and end-to-end system performance)
- Implement Ka-band experiment for New Millennium DS-1
- Create database containing DSN parameters (system temperature, antenna apertures and efficiencies, etc.) and tools for implementing these parameters in LinkScape.

RESOURCE REQUIREMENTS BY WORK UNIT:

	JPL Account #	FY98	FY99	FY00	FY01	FY02	FY03
Channel Coding	462-42253	320					
Turbo Decoder Dev.	462-42251	80					
Microwave Sys. Analysis	462-42255	150					
Total		550					

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Turbo Codes 98

WORK UNIT IN WHICH FUNDED: Channel Coding, 462-42253

WORK AREA: Communication Systems Analysis

BRIEF TECHNICAL SUMMARY:
Develop new, higher performance or lower complexity codes for deep-space communications and provide accurate performance analysis of coding schemes. Address several pending systems issues that need to be resolved before turbo codes can be used by missions. Recommend codes for standardization (CCSDS). Demonstrate new coding concepts and provide designs suitable for implementation with current technology at low cost.

JUSTIFICATION AND BENEFITS:
Channel coding is a proven cost effective method for reliable communication. There is a continuing need to provide accurate performance analyses of coding schemes, and to develop higher performance and/or lower complexity new schemes. Such improved coding systems for deep-space missions were identified in FY96, based on recent breakthroughs in turbo codes. Turbo codes will achieve about 1 dB improvement over the best codes currently in use in the DSN, with an even more important reduction in decoding complexity of about one order of magnitude.

JPL is the leader in the development of turbo codes for deep space communications. We have recommended the turbo codes for CCSDS. This year we need to resolve several peripheral issues for the application of turbo codes and we need to extend our results on serial and hybrid concatenated (turbo) codes for which JPL/Caltech has a patent application which can be used to avoid potential conflicts with the original patent by France Telecom. There is also a need to develop methods for certifying data integrity after turbo decoding.

Analytic performance bounds are needed to verify and extend simulation results at very low error rates, especially for frame error rates. New theoretical work on tightening the performance bounds can potentially yield similarly valuable insights into turbo code behavior in the "waterfall" region of the performance curve.

APPROACH AND PLAN:
Serial concatenated codes. We need to bring our knowledge on the design and performance of serial and hybrid concatenated codes with iterative decoding to the same level as the knowledge acquired on parallel concatenated (turbo) codes. We plan to perform extensive simulations to establish accurately the performance of serial codes.

System issues for turbo codes. Our interaction with new mission designers and our participation in the turbo code standardization process through CCSDS has brought forward several system issues that need to be resolved.

1. Data integrity verification --- If needed, this function could be provided by a modification of the turbo decoder (still in study phase) or by using a BCH outer code for error detection or to correct a small number of errors. The redundancy of the BCH code is estimated to introduce a small penalty of a few tenths of a dB. The new serially concatenated turbo codes could be useful to obtain much lower error floors. We need to identify and analyze the performance of error detection (CRC) or error correction (BCH) codes to provide a sufficient level of data integrity verification after turbo decoding.
2. We need to quantify the <u>effects of imperfect SNR estimates</u> on code performance.
3. Since it would be desirable to have a choice among several block lengths (e.g., bulk data transmission vs. emergency data) and each block length currently requires a different permutation stored in ROM, we need to develop fast algorithms for <u>on-the-fly permutation generation</u> and we need to analyze their performance along with algorithms already proposed.

4. We need to develop improved <u>frame synchronization methods,</u> and test and verify their appropriateness.
5. Resilience of turbo codes --- We also need to determine the turbo decoder behavior when the noise is not additive white Gaussian. We have preliminary results indicating that turbo decoders can be made adaptive (by specializing the computation of the metrics) to <u>unanticipated noise sources</u>. We need to analyze turbo codes operating in the presence of timing errors (see also proposal on coupled receiver/decoder), polarity inversion within a block, radiation effects on encoder, and RFI.
6. Another issue to be explored is the design and performance analysis of turbo codes for <u>short-block applications</u> (emergency mode communication and short-lived probes). Short-block, low-complexity turbo codes with easy synchronization method are also needed for burst communication (uplink, emergency downlink).
7. We need to address the design of turbo codes with <u>unequal error protection</u> (e.g., for headers vs. bulk data). Headers of a packetized system (SCPS?) need much lower error rates than the rest of the data. Headers could be given extra protection either by a stronger code or within the same code. This could ease the BER requirement on the non-header data.

Performance of turbo codes. We plan to continue the study of turbo code performance using <u>transfer function bounds,</u> which are useful to establish the "error floor" behavior of turbo codes without lengthy simulations. We will modify the "<u>code geometry bounds</u>" developed in this work area to tighten current bounds in the "waterfall" region of the performance curve.

We plan to complete our study on the sensitivity of turbo code performance to block size using sphere packing arguments which bound the achievable performance for a given block length. Turbo codes have been found to approach this limit within approximately 0.5 dB over a wide range of block lengths and code rates. We also plan to extend the sphere packing bounds results to turbo trellis coded modulation.

We will propose autonomous turbo decoder <u>stopping rules</u> and determine their effectiveness in improving the average decoding speed. These rules will stop iterations when convergence is satisfactory, thus reducing the average number of iterations. We plan to explore performance/computational tradeoffs for turbo decoders making <u>early decisions</u> on parts of the trellis. We will continue our effort to develop a <u>unified theoretical understanding</u> of turbo codes and their variants (parallel, serial, hybrid, self-concatenated, short/long block, etc.). Finally, we will determine block sizes for which turbo codes are preferable to conventional non-iteratively-decoded codes.

Turbo codes for optical channel. Continue to study the applicability of turbo codes to <u>optical channels</u> and compare performance with Reed-Solomon codes (This could be funded by the X2000 program in FY99 and later). We plan the following steps in designing and analyzing turbo codes for 256-PPM on a channel making independent symbol (not bit) errors:
1. Hard quantizer decoder input; Standard turbo decoder (metrics optimized for interleaved 256-PPM). Preliminary results for this case show that a simple 4-state serial code outperforms a very complex (255,127) Reed-Solomon code on the 256-PPM channel.
2. Hard quantizer decoder input; Encoder and decoder are matched to 256-PPM.
3. Decoder knows which is the best symbol and its reliability; Decoder uses best symbol reliability.
4. Decoder is given 256 soft counts; Decoder uses full soft information.

Turbo codes for very high data rates. Currently, there is strong interest for commercial applications of turbo codes at very high data rates, 100Mbps to 1Gbps (We are negotiating a follow-up study for Hughes and a collaboration with TRW on this subject). At these rates it is necessary to keep the complexity of the decoder as low as possible. We have recently developed and simulated in software a very low complexity turbo code (serial concatenation) which uses two 2-state component codes. The performance of this new code is markedly superior to a (7,1/2) convolutional code: a bit error rate of 10^{-6} can be achieved at 1.5 dB bit signal-to-noise ratio. Current technology allows us to build single chip (7,1/2) Viterbi decoders at 100Mbps. The turbo decoder for the turbo code just mentioned is simpler than a (7,1/2) Viterbi decoder, so it should be possible to achieve turbo decoding speeds in the 100Mbps to 1Gbps range. Optical links for future missions will require these data rates and could take advantage of this code. We propose to examine the performance of this code when OOK or PPM (256 to 1024) modulations are used in an optical channel. The optical channel for direct detection will be characterized by a Poisson distribution of the number of photons received per time slot, including background noise and Gaussian noise. This model will be used for the simulations.

Turbo codes experiments. Support turbo coding experiments to demonstrate code viability over real space channels (Cassini, New Millennium DS1).

DELIVERABLES:
- Design and performance of serially concatenated codes
- Resolve system issues
    - Develop methods for certifying data integrity after turbo decoding
    - Study effects of SNR estimation errors on performance
    - Develop fast algorithms for on-the-fly permutation generation
    - Develop improved frame synchronization methods
    - Develop turbo decoders that are adaptable to unanticipated noise sources
    - Develop turbo codes for short-block applications
- Develop improved theoretical bounds on the performance of turbo codes
- Study the applicability of turbo codes to optical channels
- Develop turbo codes for very high data rates
- Support CCSDS activities for standardization of turbo codes
- Support turbo coding experiments (Cassini, New Millennium DS1)

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)		320				320
Workforce (WY)		2				2
Co-funding ($K)						0
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Turbo Decoder Development

WORK UNIT IN WHICH FUNDED: Turbo Decoder Development 462-42251

WORK AREA: Communication Systems Analysis

BRIEF TECHNICAL SUMMARY:
In FY97 we have developed an FPGA-based turbo decoder that can decode (parallel) turbo codes with two component codes, each up to 64 states, up to 64 Kbits long input blocks, and code rates 1/2, 1/3, 1/4, and 1/5.

This year we will benchmark speed and performance of the decoder prototype. We plan to study the extension of the decoder design to serially concatenated codes, to use the existing decoder as a research tool to acquire error statistics, and compute bit and frame error rates for many turbo codes. We will also analyze very low complexity turbo codes/decoders for on-board applications. We will partner with industry (TelSys Inc.) to commercialize the prototype.

Using the design tools available in the Design Hub we will port the current FPGA design to an ASIC design limited to a subset of the current decoder capabilities, and we will design a suitable, versatile PC (software) interface to control the decoder.

[We could also start the development of a design tool that, by using predesigned building blocks, can synthesize the design of turbo decoders with certain parameter constraints on a suitable reprogrammable FPGA board.]

JUSTIFICATION AND BENEFITS:
There is a need to develop efficient implementations of turbo decoders to achieve the complexity savings, and to benchmark the performance (speed, power efficiency, bit and frame error rates) of new turbo coding systems. It is also necessary to understand the error characteristics of turbo decoders, which are different from those of Reed-Solomon/convolutional concatenated coding systems, so that users can understand these characteristics and how they might affect their data.   Use of the turbo decoder prototype as a research tool will facilitate the investigation of new codes, of decoder error statistics, and of frame error rates.

The performance and complexity gains offered by turbo codes are made available to near-future missions through the experience acquired in building this prototype. Partnering with industry will lead to low-cost commercial turbo decoders.

APPROACH AND PLAN:
We will demonstrate the FPGA turbo decoder prototype including frame synchronization in the symbol domain (This is contingent on the availability of frame synchronizer being built for DS-T. Otherwise we will record noise samples from a Block V receiver, and perform the frame sync in software). We will benchmark the speed and performance of the current prototype, and we will continue to investigate various important performance/complexity tradeoffs that affect the decoder implementation. We will define the final architectural design for network infusion, and partner with industry to commercialize the decoder.

We will use the prototype turbo decoder as a tool for establishing the performance of new codes especially at very low BER (near the error floor), for measuring frame error rates, for acquiring data on error statistics, and to produce detailed histograms which will be used in the design of a BCH outer code (for missions requiring very low frame error rates). We will select and analyze an outer code to correct and/or detect residual turbo decoder errors.

We will extend the turbo decoder design to develop a turbo decoder ASIC. To do this, we will take a subset of the capability in the FPGA prototype (e.g., restrict the block size and/or the number of states) and implement it on a relatively short development cycle using tools supported by the Design Hub. The challenge comes in designing a versatile interface that can be used in many applications or

environments: standalone, on a PC card, or in parallel with many other such ASICs for higher throughput. In the future this could be extended to a parallel decoder board.

By constraining the decoding to a more limited set of allowed operating parameters (e.g., constraints on the allowed code rate, block size, or number of states), we might be able to extend our work to develop a more general automated tool that combines pre-defined building blocks to produce an efficient turbo decoder implementation given a turbo code specification. This could be exceptionally valuable if we could combine it with a suitable reprogrammable FPGA board.

Finally, we will design a low-complexity turbo decoder suitable for spacecraft implementation. The design will be initially targeted for implementation on a space-qualified FPGA, and could later be extended to an ASIC if its space qualification is determined to be economically justified. This will be useful for orbiter-lander link and for command uplink.

DELIVERABLES:
- Demonstrate FPGA turbo decoder prototype. 11/97
    - Benchmark speed/performance of decoder prototype. 11/97
    - Use prototype to acquire error statistics (useful for outer code design), and compute bit and frame error rates. 3/98
    - Propose and analyze an outer code. 3/98
- Partner with industry to commercialize prototype.
- Analyze very low complexity (2+2 states) turbo code/decoders for on-board applications. 9/98

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)		80				80
Workforce (WY)		0.5				0.5
Co-funding ($K)						0
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: End-To-End Performance Analysis
WORK UNIT IN WHICH FUNDED: Microwave Systems Analysis   462-42255
WORK AREA: Communication Systems Analysis

BRIEF TECHNICAL SUMMARY:
Develop, maintain, and analyze data on new technologies (performance, costs, uncertainties, and risks) and potential future flight project requirements to: characterize the operational performance of future DSN communication systems, especially at Ka-band and optical wavelengths; evaluate technology alternatives and identify potential improvements; support flight demonstrations of advanced systems and technologies; and identify additional DSN capabilities and performance improvements to enable or enhance smaller, faster, and cheaper missions.

JUSTIFICATION AND BENEFITS:
Higher frequency communications will reduce spacecraft power consumption. Both Ka-band and optical communications meet this need. A switch to Ka-band would be an evolutionary step for the DSN since its adoption would require relatively minor changes in station electronics. On the other hand, optical frequencies would require a revolutionary step for the DSN by building completely new optical tracking stations. In either case, the end-to-end performance of the link with each frequency band must be clearly understood.

Currently, the study of the Ka-band performance is at a more advanced stage than that of the optical band. Based on these studies it is understood that Ka-band links would on the average have 4 to 6 dB performance gain over present X-Band links. However, as new techniques for use of Ka-band are developed, this advantage may become greater. Vigorous analysis is needed to characterize the end-to-end performance improvement of the link with regard to telemetry and radiometrics as new techniques are introduced for antenna pointing, and telemetry decoding and demodulation. Furthermore, it is necessary to better understand the effect of natural processes such as atmospherics and solar scintillation on the link in order to perform a more accurate analysis of its performance.

Simulations will be used to characterize the end-to-end performance of the Ka-band link using models for different subsystems (e.g., antenna pointing, receivers, modulator) and natural processes that may affect the link. Experiments using spacecraft and ground equipment could be used to further refine the subsystem models, producing a more accurate link performance analysis.

APPROACH AND PLAN:
The objectives of this work unit will be accomplished by: establishing and maintaining a body of data on new systems, technologies, and potential DSN needs; developing models to characterize and project operational performance of present and future systems; performing comparative analyses to evaluate alternative technologies and identify potential DSN improvements; and supporting advanced mission studies and developing operational strategies to facilitate adoption of advanced technologies.   Specific plans for FY98 are:

1. Continue comparative analysis of Ka-band and X-band system performance and operations. Update and forecast Ka-band link advantages versus X-band based on anticipated technology development. Develop Ka-band operations concept providing low-cost, highly operable, robust, high-performance downlink telemetry service. Continue collecting WVR data and update weather model for Ka-band links. Update Ka-band link budget.
2. Continue to study scintillation effects on telemetry performance for different error-correcting codes. Extend the scintillation model to radiometrics at Ka-band and X-band. Determine the appropriate model parameters and perform simulations.
3. Collaborate with the Antenna Systems work area to assess G/T versus SNR for different antenna pointing techniques: Conscan, array feed, and monopulse. For given pointing error statistics, determine the system loss, that is, how pointing affects the end-to-end performance of the link.
4. Conduct Ka-band experiment for New Millennium DS-1 to compare the performance of Ka-band with X-band, and correlate downlink data integrity with predicted SNR and WVR data.
5. Support the development of LINKSCAPE (a software tool for communication link design) by creating a database containing DSN parameters (system temperature, antenna apertures and

efficiencies, etc.). Develop analysis tools to assess the cost and performance of DSN improvements. Interface with new missions to provide the updated DSN capabilities and analysis tools.

6. Improve models for spacecraft oscillator phase noise at Ka-band and evaluate effect on system performance.

DELIVERABLES:
- Continue comparative analysis of Ka-band and X-band system
- Continue study of scintillation effects on telemetry performance
    - Extend scintillation model to radiometrics at Ka-band and X-band
- Assess G/T versus SNR for different antenna pointing techniques
    - Determine system loss (how pointing affects G/T and end-to-end system performance)
- Implement Ka-band experiment for New Millennium DS-1
- Create database containing DSN parameters (system temperature, antenna apertures and efficiencies, etc.) and tools for implementing these parameters in LINKSCAPE.

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)		150				150
Workforce (WY)		1				1
Co-funding ($K)						0
Projected Savings ($K)						0